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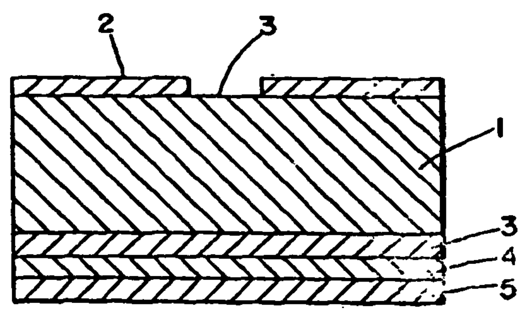

(57) Abstract

An optical filtering method and element for selectively transmitting radiation incident upon a first surface of the filtering element. The method comprises the steps of identifying the constituents of the filtering element, including an optically suitable substrate and a translucent polymeric coating formulation having desired optical transmission properties, fabricating a polymeric coating based on that formulation, and applying the coating to the substrate in a thin layer. The coating may be applied by screen-printing, pad printing or spray coating. The invention is useful in aerospace lighting applications including night vision lighting applications.

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OPTICAL FILTERING METHOD AND ELEMENT

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention is concerned generally with optical filtering elements, and more particularly, with optical filtering elements for aerospace lighting applications.

An optical filtering element placed between a light source and an observer selectively transmits to the observer radiation incident upon the surface of the filtering element adjacent the light source. Accordingly, an optical filter may be used to selectively limit the spectrum of emitted radiation that reaches the observer, such that the spectrum of radiation incident upon the eye of an observer has desired photometric, colorimetric, daylight readability or night vision properties.

The optical filtering elements used today in aerospace lighting applications typically employ element- or salt-doped glass substrates to achieve desired optical transmission properties. Doped glass filters for new aerospace lighting applications are difficult and costly to develop and fabricate because the transmission-altering elements or salts are incorporated into the glass. Modification of the optical transmission properties of an existing doped glass filter generally is precluded for the same reason. In addition, dopedglass filters provide only a limited range of optical transmission properties.

Doped glass filters also may be incompatible with the severe environmental and thermal conditions to which aerospace lighting devices may be exposed. Specifically, existing filters having desired optical transmission properties may undergo devitrification and delamination on exposure to salt fog. Such filters also may undergo delamination or other damage to filter components on exposure to elevated temperatures.

Consequently, a need exists for optical filtering elements that possess a broader range of optical transmission properties than doped glass filters, that are resistant to the severe environmental and thermal conditions to which aerospace lighting devices may be exposed, that are capable of being developed and fabricated quickly and inexpensively, and that are capable of being modified to provide different optical transmission properties.

The present invention provides an optical filter element and method designed to satisfy one or more of the foregoing objectives. In particular, the method of the present invention yields a translucent optical filtering element having controlled transmittance and chromaticity suitable for use in aviation lighting applications including night vision applications. In accordance with the teachings of the invention, an optically suitable substrate and a translucent polymeric coating may be selected such that application of a thin layer of the coating to at least one surface of the

substrate yields an optical filtering element having desired optical transmission properties. The polymeric coating may be fabricated and applied in a thin layer to a surface of the substrate.

The following drawings and detailed description will more thoroughly explain the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front elevational view of an optical filtering element of the present invention having a nomenclature coating pre-applied to a surface of a substrate to define a legend thereon;

FIG. 2 is a diagrammatic cross-sectional view of an optical filtering element of the present invention having a single layer of polymeric coating applied to a surface of a substrate; and

FIG. 3 is a diagrammatic cross-sectional view of an optical filtering element of the present invention having multiple layers of polymeric coating applied to a surface of a substrate.

DESCRIPTION OF PREFERRED EMBODIMENT(S)

In a preferred embodiment of the present invention, an optical filter may be prepared by the steps of selecting the filter constituents, including an optically suitable substrate 1 and a polymeric coating formulation 4 as shown in FIG. 2, fabricating the polymeric coating based on that formulation, and applying the coating to the substrate.

The intensity of light after passing through a transmissive solid, such as an optical filtering element may be determined by

$$I = I_o e^{-ax}$$

where I is the intensity of light after passing through a solid of thickness x, I_o is the intensity of light at x = 0, and a is a substance-dependent absorption coefficient. The transmittance of light is given by

$$T(\ ) = \frac{I}{I_o} = e^{-ax}$$

where T is transmittance at a given wavelength, . The foregoing relationship also may be expressed in the form of the Beer-Lambert law,

$$\text{Ln } T(\ ) = b(\ ) kx$$

where b is a substance-dependent extinction coefficient at the specified wavelength, k is the concentration of the transmissive solid and x is the thickness of the solid. The transmittance of a collection of solids is the product of the individual transmittances of the components in the collection. Accordingly, the transmittance of an optical filtering element comprised of a collection of solids is a function of the thickness and concentration of each of the constituents in the collection.

The chromaticity of an optical filter is dependent upon the spectral distribution of visible light transmitted, which

is related to the spectral extinction coefficient, b( ), of each transmissive solid. As such, the chromaticity of an optical filtering element will be determined by those wavelengths of visible light which are selectively transmitted. Chromaticity coordinates for an optical filter may be determined from the spectroradiometric methods as described by Miller and Schneider, "Colorimetry: Methods and Tools," in The Photonics Design and Applications Handbook 1991, pages H-32 through H-40, which is incorporated herein by reference.

The constituents of the filtering element may be selected in view of its intended end use, which may include consideration of the light source to be used with the filtering element, the environmental conditions to which the filtering element will be exposed, and the desired optical transmission properties of the filtering element. The desired optical transmission properties may be determined from a filtering element specification, or from examination of a sample filtering element or color chip.

An optically suitable substrate may be selected based upon the foregoing considerations. The substrate may be plastic, glass or other vitreous material, and may comprise one or more layers of substrate material. The size and shape of the substrate may be selected to accommodate the light source, which may be a conventional fluorescent or incandescent light source. The composition of the substrate

may be selected to withstand environmental conditions or to impart particular optical transmission properties to the filtering element. For example, a substrate capable of blocking substantial amounts of infrared radiation may be used to achieve desired optical transmission properties or to shield from heat a coating applied to a substrate, for example, when a filtering element is used with an incandescent light source. A nomenclature coating 2 may be pre-applied to a surface of a substrate 1 to define a legend 3 thereon which may be illuminated by light transmitted from a light source through the legend portion of the substrate, as shown in FIG. 1.

A polymeric coating formulation also may be selected based upon the foregoing considerations. The pigments used in the coating formulation generally are crystalline solids capable of altering the transmission of radiation within the visible and infrared spectra, from about 400 nanometers to about 1100 nanometers.

The pigment(s) and concentration(s) to be included in a particular formulation may be determined by evaluating test slides in view of the thickness of the coating layer to be applied to the substrate. The test slides may consist of available pigments in various concentrations, uniformly coated onto optically transparent substrates. One or more test slides may be positioned adjacent an appropriate light source, such as a lamp and lampholder assembly intended for

use with a particular filtering element. The radiation transmitted from the light source through the test slides may be evaluated by photometric and/or radiometric methods, using, for example, an EG&G Gamma Scientific C-11ASR NVIS spectroradiometer available from EG&G Gamma Scientific, Inc., San Diego, California. The optical transmission properties of test slides derived from such methods, and the known optical transmission properties of a substrate, may be combined in accordance with the Beer-Lambert law. The combination of test slides calculated to result in an optical filtering element having desired optical transmission properties when applied to at least one surface of a chosen substrate identify the pigment(s) and concentrations(s) to be included in the polymeric coating.

The identified pigment may be dispersed in a polymeric vehicle, preferably with the aid of a wetting agent. The polymeric vehicle, which may be selected for resistance to adverse environmental conditions such as salt-fog and temperature extremes to which the filtering element may be exposed, may include a polymeric resin solution, for example, 60 percent by weight polyester resin in a suitable solvent such as 4-butoxyethanol. The vehicle also may include cross-linking and catalytic components appropriate to the polymeric component, as well as such components as flow additives, thinners, for example, 4-butoxyethanol, and retarders to modify the coating characteristics. The

concentration of flow additives added to the coating formulation may vary with the oil absorbance of the particular pigment(s) used.

Coating fabrication may consist of the steps of pre-mixing the pigment and the polymeric resin, dispersing the pigment in the resin, and preparing a let-down coating mixture. In the pre-mixing step, a wetting agent, for example, 70 percent by weight aromatic ester in a suitable solvent such as mineral spirits, may be added to a predetermined mass of a pigment. The mass of pigment to be included in the coating formulation may be given by

$$m_p = MC$$

where m_p is the pigment mass, M is the theoretical total mass of the coating, and C is the desired pigment concentration. The mass of the wetting agent may be 0.002M. The wetted pigment may be combined with a predetermined mass of resin. The mass of the resin to be included in premix may be given by

$$m_v = \frac{M(1-C)}{2.847}$$

where m_v is the mass of the resin in the premix.

The pigment may be dispersed in the resin by milling, preferably using a three-roll mill. Assuming uniform loss, the yield ratio from the milling step is given by

$$Y = \frac{2.847(W')}{M\,(1.847C + 1.006)}$$

where Y is the yield ratio and W' is the mass of the premix after grinding.

A cross-linking agent, such as a modified melamine resin, a catalyst appropriate to the resin, a retarder appropriate to the resin, a flow additive, for example, 13 percent by weight medium-chain hydrocarbon ester in a suitable solvent such as an aromatic hydrocarbon, and additional resin may be added to the milled mixture in the let-down step. The masses of the let-down components to be added to the milled mixture may be as set forth in Table I:

Table I: Mass of Let-down Constituents

Constituent	Mass
cross-linker	9.280×10^{-2} YM (0.971 - C)
catalyst	0.0075YM
flow additive	0.02YM
resin	$\frac{YM}{2.847}$ (1.507 - 1.583C)

Flow additives, for example, a medium-chain hydrocarbon ester or an aromatic poly(siloxane) in an aromatic hydrocarbon solvent, may be added to the let-down mixture before the coating step. For screen-printing, the mass of the let-down mixture preferably comprises 81 percent of the mass of coating to be applied and the mass of each of the two preceding flow additives comprises 9.5 percent of the mass of the coating. A thinner or a retarder also may be added to

the let-down mixture before the coating step. The concentration of pigment in a coating mixture may be decreased if desired by adding an appropriate quantity of an unpigmented polymeric coating before applying the coating mixture.

The coating 4 preferably is applied to a substrate 1 as shown in FIG. 2 to form a substantially uniform translucent coating layer having a thickness of approximately 0.2 mil or more. The substrate may be cleaned by any suitable method prior to coating. The coating may be applied to a substrate by screen-printing, spray coating or pad printing. The size and shape of the substrate may affect the coating application method selected. For example, a substrate having an irregular contour may not be suitable for coating application by screen-printing. The coating preferably is screen-printed onto a substrate using a No. 160 mesh monofilament polyester screen. Other screen types and sizes also may be used.

Typically, the coating will be applied to the surface of the substrate adjacent to the light source, to protect the coating from physical damage and reduce exposure to environmental conditions. However, the coating also may be applied to the surface of the substrate away from the light source to prevent melting of the coating when a high-intensity incandescent light source is used.

After the coating is applied, the filtering element may be cured at room temperature or in an oven, for example, at

260-450°F for 10-90 minutes. Multiple layers of polymeric coatings 3-5 may be applied sequentially to a substrate as shown in FIG. 3 to achieve desired optical transmission properties in accordance with the Beer-Lambert law. Multiple layers of polymeric coating may be required when the desired concentration of pigment is high enough that inclusion of that concentration of pigment in a single coating mixture may interfere with milling or coating. The maximum pigment concentration in a coating may range from about nine percent to about twenty percent by mass, depending upon the pigment(s) used.

The method of the present invention may be used to prepare optical filtering elements adapted for night vision lighting applications. The polymeric coatings used for night vision applications may include an infrared-blocking pigment. The infrared-blocking pigment(s) may be included in a polymeric coating layer separate from the remaining pigments selected to achieve desired optical transmission properties for such applications. Infrared-blocking substrates also may be used to achieve the optical transmission properties desired for night vision applications.

EXAMPLE

Two layers of polymeric coating were applied to the surface of a suitable clear substrate adjacent a light source to obtain a Green A optical filtering element.

The premix for a first polymeric coating was prepared by combining 2.10 grams of a suitable pigment and 0.06 grams of an aromatic ester-type wetting agent with 9.80 grams of a polyester resin solution. The wetted pigment was dispersed in the resin by milling. The mass of the mixture after milling was 10.692 grams, for a yield ratio of 0.894. In the let-down step for that coating, 2.24 grams of a modified melamine resin-type cross-linker, 0.20 grams of a catalyst, 0.54 grams of a medium-chain hydrocarbon ester flow additive and 13.16 grams of additional resin solution were added to the milled mixture. 7.90 grams of the let-down mixture was combined with approximately 0.93 grams of a medium-chain hydrocarbon ester flow additive and approximately 0.03 grams of an aromatic poly(siloxane) flow additive before applying the coating.

The premix for a second polymeric coating was prepared by combining 1.88 grams of a suitable infra-red blocking pigment and 0.05 grams of the wetting agent used previously with 8.12 grams of a polyester

resin solution resin. The wetted pigment was dispersed in the resin by milling. The mass of the mixture after milling was 9.00 grams, for a yield ratio of 0.895. In the let-down step for that coating, 1.86 grams of a modified melamine resin-type cross-linker, 0.17 grams of a catalyst, 0.45 grams of a medium-chain hydrocarbon ester flow additive, and 10.91 grams of additional resin solution were added to the milled mixture. 9.63 grams of the let-down mixture was combined with approximately 1.14 grams of a medium-chain hydrocarbon ester flow additive and approximately 1.14 grams of an aromatic poly(siloxane) before applying the coating.

As shown in FIG. 3, the first coating 3 was applied to a substrate 1 by screen-printing using a 160 mesh monofilament polyester screen and allowed to cure. A layer of the second coating 4 was applied to the substrate over the cured first coating layer 3 by the same screen-printing procedure. A second layer of the second coating 5 was applied to the substrate over the cured first layer of the

second coating 4 using the same method. Each of the coating layers applied to the substrate was approximately 0.5 mil thick.

The present invention may be useful for interior aircraft lighting applications such as cockpit lighting, rest room lighting and illuminated signs, for exterior aircraft lighting such as wing-position and anti-collision lighting, and for ground lighting applications such as hangar, terminal, and runway lighting.

The optical filtering element and method of the present invention, and many of their attendant advantages will be understood from the foregoing description. It will be apparent that various changes may be made in the form and construction of the parts thereof without departing from the spirit and scope of the invention or sacrificing all of its material advantages.

What is Claimed is:

1. A process of making an optical filtering element, comprising the steps of:

selecting an optically suitable substrate suitable for aerospace lighting applications and a translucent polymeric coating formulation, each having desired optical, thermal and environmental properties;

fabricating a polymeric coating in accordance with said coating formulation; and

applying said coating to a surface of said substrate.

2. The process of claim 1 wherein said optical properties comprise a predetermined transmittance.

3. The process of claim 1 wherein said optical properties comprise a predetermined chromaticity.

4. The process of claim 1 wherein said coating application step is performed by screen-printing.

5. The process of claim 1 wherein said coating application step is performed by spray coating.

6. The process of claim 1 wherein the coating application step is performed by pad printing.

7. The process of claim 1 wherein said polymeric coating selectively transmits radiation in the visible spectrum.

8. The process of claim 1 wherein said polymeric coating selectively transmits radiation in the infrared spectrum.

9. The optical filtering element produced by the process of claim 1.

10. The optical filtering element of claim 9 wherein said element selectively transmits radiation in the visible spectrum.

11. The optical filtering element of claim 9 wherein said element selectively transmits radiation in the infrared spectrum.

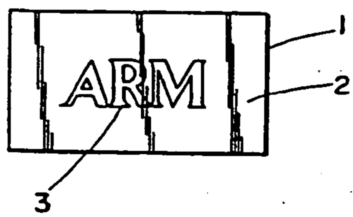

Fig. 1

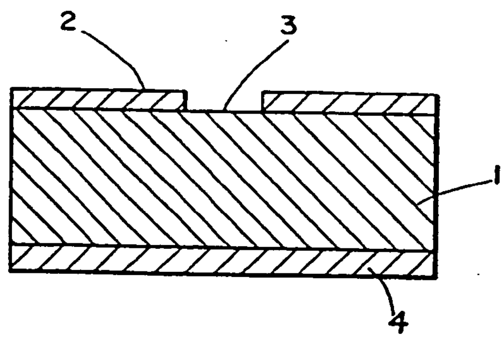

Fig. 2

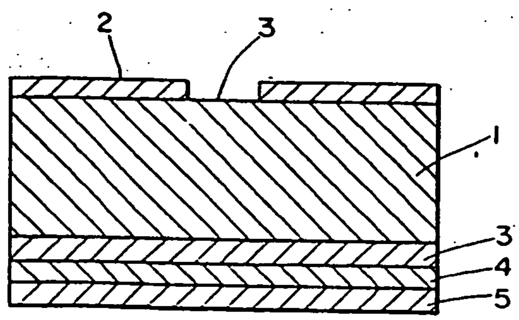

Fig. 3

SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/11817

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G02B 1/04, 5/22
US CL :359/350, 359, 885
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/350, 359, 885

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 3,696,263 (WACHER) 03 October 1972 (see entire document)	1-11
X	US, A, 4,601,532 (MUSSER ET AL.) 22 July 1986 (see entire document)	1-11
X	JP, A, 2-204,704 (INSATSU KK) 14 August 1990 (see entire document)	1-11
A	JP, A, 4-401 (SHIMA) 06 January 1992 (see entire document)	1-11
A	JP, A, 1-237503, (CANON KK) 22 September 1989 (see entire document)	1-11

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,016,985 (KALMANASH ET AL.) 21 May 1991 (see entire document)	1-11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/11817

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

PTO APS: Polymer w/5 filter and optical filter w/10 (visible light or infrared light); plastic or polymer w/3 (substrate or base or transparent or translucent); optical filter w/25 (screen print? or pad print? or spray)